

MAR 7 1979

Item 830-4-15

NAS1-60:1415

NASA Technical Paper 1415

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Measurement System Used in the NASA
Global Atmospheric Sampling Program**

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FEBRUARY 1979

NASA

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SUMMARY

The condensation-nuclei (Aitken particle) measuring system used in the NASA Global Atmospheric Sampling Program is described. The system uses a modified version of a commercial instrument that has been repackaged to operate unattended in an aircraft environment. Included in the package is an NASA-designed sample pressurization system. The condensation-nuclei monitor (CNM) can detect particle concentrations of less than 10 CN/cm^3 with a full-scale range of 1000 CN/cm^3 at flight altitudes between 6 and 13 kilometers. The monitor has a noise level equivalent to less than 5 CN/cm^3 at these altitudes. The monitor sensor is capable of measuring concentration with an error (1 standard deviation) of ± 6.6 percent of reading (at 100 CN/cm^3) when calibrated against a Pollak counter for a given size and type of particle. A description of the calibration system is included in the paper. An appendix describes the test program used to obtain Federal Aviation Administration certification and for reliability and quality assurance.

INTRODUCTION

A condensation-nuclei (Aitken particle) measurement system has been certified for operation on commercial aircraft and is being flown as part of the NASA Lewis Research Center's Global Atmospheric Sampling Program (GASP). That system is described in this paper. The condensation-nuclei monitor (CNM) used in this system is a modified version of a commercial instrument made by Environment/One Corp. of Schenectady, N.Y. This was the only commercially available instrument that could be readily modified and used in GASP. The modifications done by Environment/One included changing the readout circuit, adding control circuits for automatic operation, repackaging it into an ARINC (Aeronautical Radio, Inc., of Washington, D.C.) instrument enclosure, and making other changes to meet airline environmental requirements for shock, vibration, and electromagnetic interference. In addition, the Lewis Research Center modified the sensor-system electronics, the timing, and the flow system so as to increase sensitivity. Also, a new pressurization system, designed by the author and installed by Lewis personnel, increases the particle concentration reaching the detector by a factor equal to the density ratio change occurring during pressurization. With this addition the monitor can measure concentrations of less

than 10 condensation nuclei per cubic centimeter (CN/cm^3). This pressurization system replaced the constant-volume system supplied with the monitor.

The Global Atmospheric Sampling Program instruments measure a number of atmospheric constituents including ozone, carbon monoxide, water vapor, and the concentration of condensation nuclei. These constituent measurements are being made in the upper troposphere and lower stratosphere (6- to 13-km altitude) by means of an automatic unattended system installed on a number of airline-operated B-747 aircraft. Details of the aircraft system are given in references 1 and 2. A series of reports (refs. 3 to 8) describe GASP flight routes, dates, data-processing procedures, and data tape specifications. Constituent measurement data obtained from the systems are available on tape through the National Climatic Center, Ashville, North Carolina.

This paper describes the GASP CN-measuring system in sufficient detail so that a potential user can judge the quality of the CN data and the measuring capability of the CNM. Included are descriptions of the aircraft flow and data systems as they relate to the CN measurement, the modifications made to the CNM to increase sensitivity so that concentrations of less than $10 \text{ CN}/\text{cm}^3$ can be measured, and the pressurization system along with typical flows and the pressures required for proper monitor operation. The method used to calibrate the GASP CNM is discussed. The certification test program and reliability tests performed on the monitor are described in the appendix.

DESCRIPTION OF AIRCRAFT MEASUREMENT SYSTEM

A schematic diagram of the CN-measurement flow system is shown in figure 1. Sample air enters the system through a 22-millimeter-inside-diameter probe that extends beyond the boundary layer of the aircraft. Total flow rate into the probe is approximately 2000 standard liters per minute (std. liters/min). From the probe, the flow passes into a conical diffuser section in which the flow cross-sectional diameter increases to 76 millimeters. Downstream of the diffuser, a secondary probe, 11 millimeters in inside diameter, picks up a 25-std. liter/min sample for the GASP-system analytical instruments. The remaining 1975 std. liters/min passes through a particle filter and exits the system through an overboard exhaust port. Downstream of the secondary probe, the 25-std. liter/min flow is divided into 20 for the pressurized analytical instruments and 5 for the CNM. The CNM is connected to the flow divider through a 17-millimeter-inside-diameter by 8-meter-long stainless-steel tube. In addition to the sample flow, the CNM uses 17 std. liters/min of cabin air for pressurization. The monitor exhaust is connected to a second overboard exhaust port. The total pressure drop across the CNM from sample inlet to exhaust is 7.5 kilopascals,

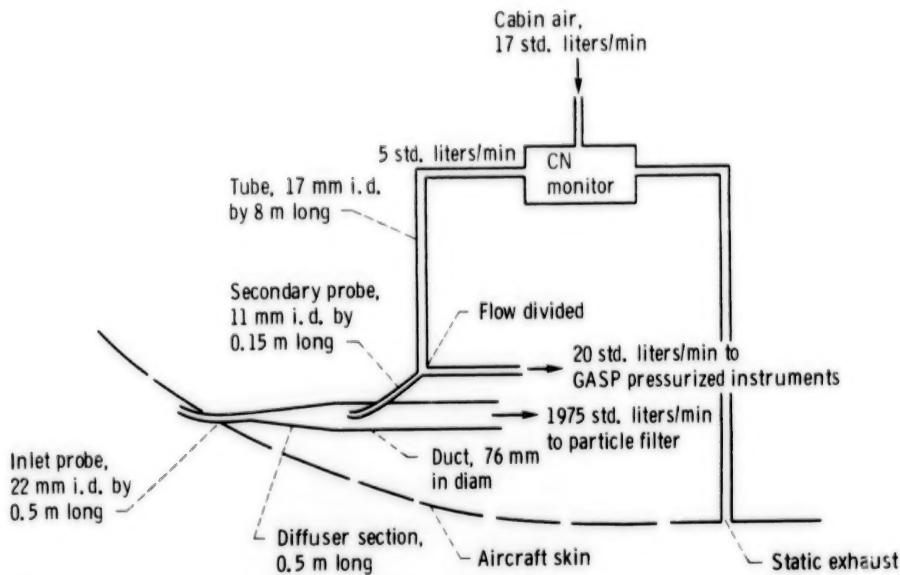


Figure 1. - Schematic diagram of condensation-nuclei-measurement flow system with typical flows at altitudes between 10 and 13 kilometers.

with an inlet pressure of 28 kilopascals absolute. This is equivalent to conditions at a 12-kilometer flight altitude.

The particle diffusion losses occurring in the 8-meter-long tube were calculated by using equation (39.3) of reference 9. The calculations indicate that as much as 3, 7, and 45 percent of particles with diameters of 0.02, 0.01, and 0.002 micrometer, respectively, might be lost in the tube. Losses were not measured on the aircraft installations, but some test data are given in the operational test section of this paper on the loss in a similar length of tubing.

A 60-minute data-recording cycle is programmed into the GASP data management and control computer. The cycle is divided into twelve 5-minute intervals during which six measurement intervals are alternated with six calibration intervals. Sixteen seconds of data is recorded on magnetic tape at the end of each 5-minute interval. During each calibration interval, the computer activates one of the six control signals, which in turn activates one of two test modes designed into the CNM. In the first mode, which is activated three times each hour, the sample air is valved through a filter built into the monitor to determine the monitor output when there are no particles in the sample flow. In the second mode, which is also activated three times each hour, the monitor generates a test voltage that shows that the detector, the light source, and the electronics are functioning properly.

Monitor output, cabin pressure, cabin air temperature, outside static air temperature, and flight altitude are measured and recorded in order to calculate the CN con-

centration in the sample air. The ambient-air concentration of particles measured by the monitor system is calculated from the following equation:

$$CN_{amb} = S \frac{P_{sap}}{P_{cab}} \frac{T_{cab}}{T_{sat}} (V_{meas} - V_{zero}) \quad (1)$$

where

CN_{amb}	CN concentration at outside ambient conditions, CN/cm^3
S	monitor sensitivity, $600 CN/cm^3 \cdot volt$
P_{sap}	outside static air pressure at flight altitude, kPa abs
P_{cab}	cabin pressure, kPa abs
T_{cab}	cabin or monitor temperature, K
T_{sat}	outside static air temperature, K
V_{meas}	output of monitor with sample air, volts
V_{zero}	output of monitor with particle-free air, volts

This equation assumes that the monitor output is a linear function of concentration over the measurement range. The pressure and temperature ratios are included in the equation as a result of pressurization-system operation, which is described in the next section. The CNM is adjusted to have a sensitivity of $600 CN/cm^3 \cdot V$ when the inlet pressure equals the cabin pressure. This sensitivity is based on available data, which indicate that the expected concentration levels would range from 0 to $1000 CN/cm^3$ on typical GASP flights. The CNM output is a 0- to 5-volt full-scale signal. Because the data system does not measure negative voltage, the monitor zero is normally set to 0.5 volt - for a full-scale range of $2700 CN/cm^3$ with a monitor sensitivity of $600 CN/cm^3 \cdot V$. The full-scale output is equivalent to $1000 CN/cm^3$ for typical flight conditions when the pressure and temperature corrections are applied by using equation (1).

DESCRIPTION OF CONDENSATION-NUCLEI MONITOR

The condensation-nuclei monitor is designed to measure the volume concentration in a sample of uncharged particles with diameters greater than 0.002 micrometer. The CNM consists of two systems: a sensor system and a pressurization system. The sensor system uses a cloud chamber in which conditions are established that allow CN particles to act as nucleation sites for the formation of a uniform-size-water-droplet cloud. The density of the cloud, which is proportional to the number of particles

present, is determined by using a light-attenuation measurement technique. Because the cloud chamber does not function properly at flight-altitude pressure levels, a pressurization system is built into the monitor. The pressurization system, designed and installed by NASA Lewis personnel, uses filtered cabin air to increase the sample pressure to that of the aircraft cabin, at which pressure the cloud chamber is operated. This system replaced the system supplied with the CNM.

The monitor with the dust cover removed is shown in figure 2. Both the sensor and pressurization systems are built into a single ARINC $1\frac{1}{2}$ Air Transport Racking (ATR) chassis. Overall dimensions are 39 centimeters wide, 50 centimeters long, and 19 centimeters high. All plumbing connections are made through the front panel, and all electrical connections are made through an ARINC connector on the monitor back. The instrument is powered by 115 volts ac (400 Hz) and requires an external source of 28 volts dc for mode control.

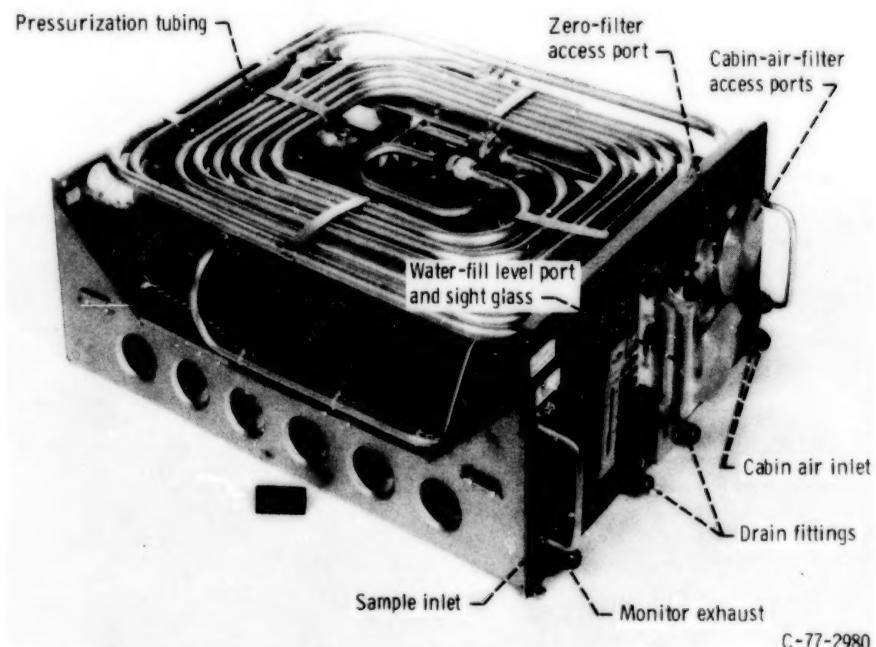


Figure 2. - Condensation-nuclei monitor.

Pressurization System

In the pressurization system, cabin air is used as an "air piston" to compress the sample. The system is designed to prevent the mixing of sample air with cabin air. The pressurizing volume is a 1-centimeter-diameter, 3-meter-long tube into which the sample air is drawn. The inlet is then closed and the tube is backfilled with filtered

cabin air until cabin pressure is reached. The sample is thus trapped at the inlet end of the tube, from which the sensor system draws its sample. With this arrangement, the particle concentration measured by the sensor system is higher than that outside the aircraft by a factor equal to the density ratio. The density ratio is included in equation (1) in the pressure and temperature ratio terms.

A flow diagram of the pressurization system is shown in figure 3. The system has four basic components:

(1) Four check valves: These are "swing" check valves whose cracking pressures have been adjusted to between 0.5 and 1.0 kilopascal (2 to 4 in. of water).

(2) Two pressurizing tubes: Each pressurizing tube consists of a 3-meter-long, 1-centimeter-inside-diameter aluminum tube in which a spiral strip (10-cm pitch) has been inserted to control the interface, or mixing region, between the sample air and the filtered cabin air. The length of tubing required was found experimentally and is such as to ensure that none of the sample reaching the sensor system is mixed with cabin air. The length depends on tube diameter, operating pressure ratio, volume between the two check valves, pressurizing cycle rate, and sample flow rate to the sensor system.

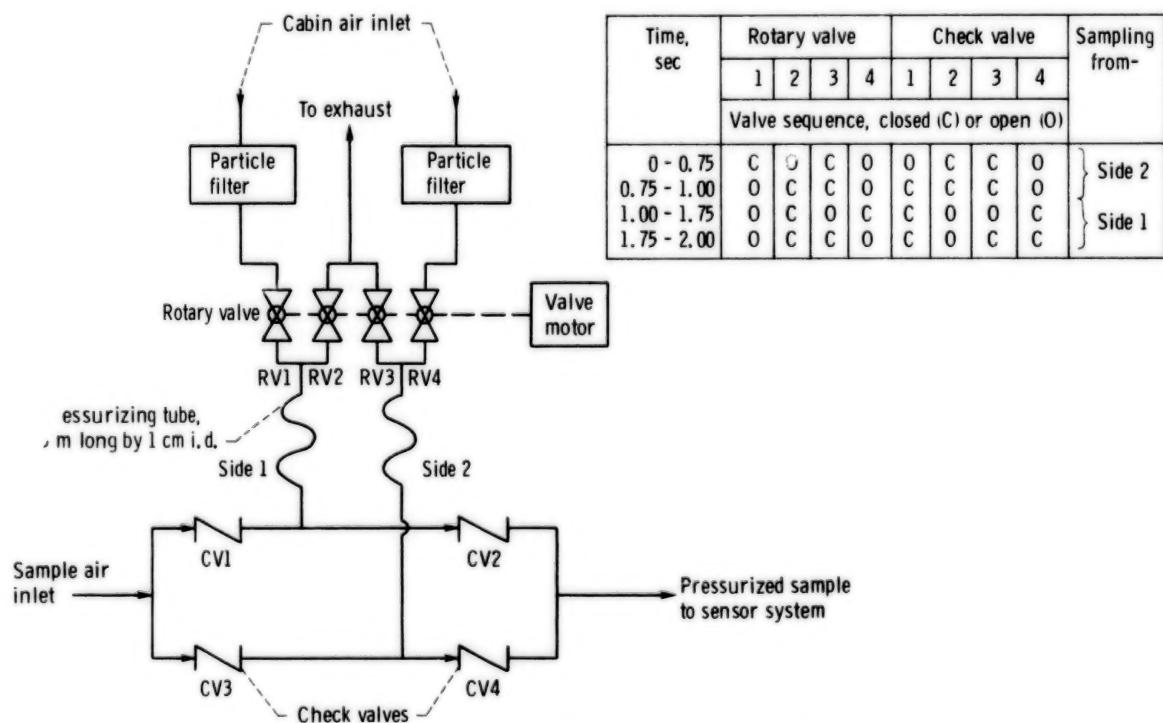


Figure 3. - Pressurization system and valve sequence.

(3) Rotary valve: The rotary valve consists of four separate two-way valves machined into a single rotor. The valves open and close as a function of time, as shown in the valve sequence chart in figure 3. The rotor is driven at 30 rpm with a 400-hertz-hysteresis gearhead motor.

(4) Two particle filters: Ideally, the particle filters are not required since the length of pressurizing tubing was chosen so that no diluted sample air would enter the sensor system. However, the filters are used to maintain cleanliness in the pressurizing tubes.

As shown in figure 2 the sample enters the monitor through the top fitting on the left side of the front panel and leaves the monitor, combined with pressurizing air, through the lower fitting. Cabin air enters through the two fittings on the right side of the front panel. The two large circular disks on the right side are access ports for the cabin-air particle filters. The pressurizing tubes are installed on top of the monitor.

The pressurization-system operating valve sequence (fig. 3) is as follows: At time zero of a given cycle, rotary valve 2 (RV2) opens and the pressurizing tube is exhausted until sample inlet pressure is reached. At this time, check valve 1 (CV1) opens and sample air is drawn into the tube. After 0.75 second, RV2 closes and RV1 opens to allow filtered cabin air to backfill and pressurize the sample. When cabin pressure is reached, the sensor system is able to draw an air sample through CV2 for approximately 1 second, after which the valve sequence is repeated. At the same time, side 2 - operating out of phase with side 1 - is supplying a sample to the sensor system while side 1 is being exhausted and filled.

A set of measurements was made to establish the range of pressures and flows over which the system would operate without diluting sample air with cabin air. The exhaust pressure required for nondilution is shown in figure 4 as a function of minimum inlet pressure. For nondilution, the exhaust and inlet pressure combination must be in the operating region (to the right of the curve). These data are based on an average sample flow rate of 1.25 std. liters/min into the sensor system. The figure shows that a 5-kilopascal pressure difference is required between the exhaust and the inlet to operate the monitor pressurization without dilution at an inlet pressure of 20 kilopascals absolute. The pressure difference decreases slightly as the inlet pressure increases.

Average sample flow rate into the monitor was measured as a function of inlet pressure for three exhaust pressures (fig. 5). Also plotted is the minimum inlet pressure to ensure nondilution, as a function of exhaust pressure. The operating line for monitors in the GASP aircraft system is also shown. This operating line is well within the nondilution region, with flow rates into the monitor ranging from 5 to 8 std. liters/min.

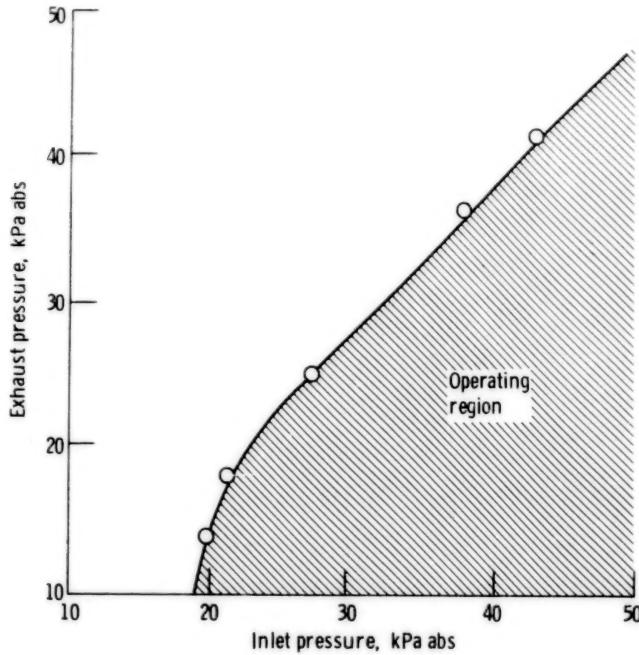


Figure 4. - Exhaust pressure as function of minimum inlet pressure to ensure no mixing of sample and pressurizing air.

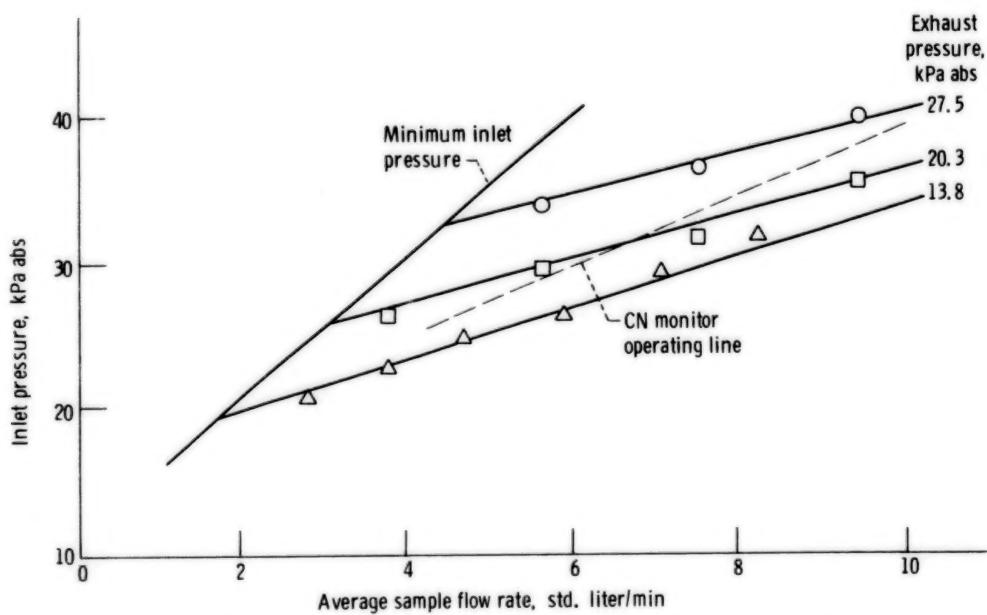


Figure 5. - Average sample flow rate as function of inlet pressure for three exhaust pressures.

Sensor System

The sensor system is designed to provide conditions that encourage particles to act as nucleation sites for water-droplet growth. The conditions are achieved through an adiabatic expansion of the air sample after it has been saturated with water vapor. This expansion is caused by a rapid increase in the cloud-chamber volume. The expansion is sufficient to obtain a supersaturation of 420 percent.

A schematic flow diagram of the sensor system is shown in figure 6. The sensor system consists of a cloud chamber, an expansion chamber, a humidifier, and a rotary

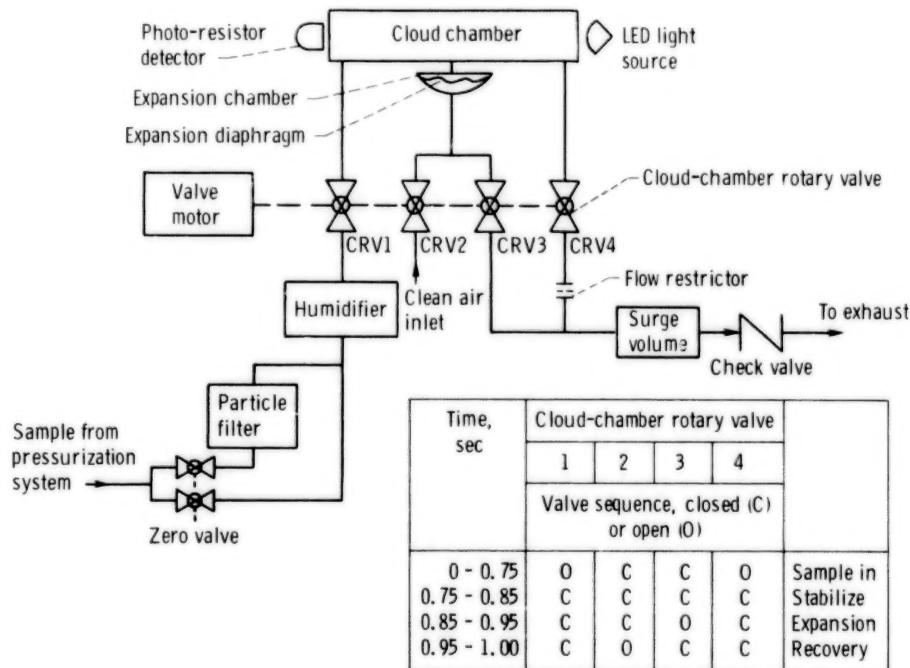


Figure 6. - Sensor flow system and cloud-chamber valve sequence.

valve. The cloud chamber, the expansion chamber, and the humidifier are the same components that Environment/One Corp. uses in their commercial high-sensitivity condensation-nuclei monitors. Some changes have been made in the components by NASA Lewis. The components as well as the changes and their effects are described here:

(1) Cloud chamber: The cloud chamber is a black, anodized-aluminum cylinder 1.1 centimeters in inside diameter by 9.2 centimeters long. The air sample enters and exits the cylinder approximately 1 centimeter from each end. The expansion chamber is connected to the side of the chamber midway between the ends. A light-emitting-diode (LED) light source with collimating lens assemblies and a photoresistor

with collector lens assemblies are attached to opposite ends of the cylinder. The light beam, with a beam diameter of approximately 0.4 centimeter, traverses the cylinder centerline. NASA Lewis personnel have installed resistive heaters on both the collimator and collector lens assemblies that add 1/2 and 1 watt of heat, respectively. The purpose of these heaters is to raise the assembly temperature 2 to 4 degrees Celsius above the cylinder temperature. This eliminates the slight fogging of the lenses that tends to occur during the expansion process. In tests, this heat addition reduced random variation in the monitor output signal, thereby allowing measurement of lower concentrations.

(2) Expansion chamber: The expansion chamber is a spherical segment with a base diameter and height of about 5 and 0.5 centimeter, respectively. The base is connected to the cloud chamber through a short length of 0.4-centimeter-diameter tubing. A diaphragm is stretched across the base and, when drawn into the spherical segment, causes the cloud-chamber volume to increase.

(3) Humidifier: The humidifier is an aluminum block into which has been machined a rectangular hole 6 centimeters long, 2.5 centimeters wide, and 5 centimeters high. Baffles are inserted in the hole, and both the hole and the baffles are lined with a felt-like material. This material, which is wetted through wicking action, supplies water vapor to the air sample. A thermistor is used to sense and control the water level in the humidifier. Distilled water is supplied from a 1-liter reservoir in the monitor. This amount of water lasts for more than 200 operating hours. The reservoir is filled through an opening in the top of the water-level sight glass located on the front panel (fig. 2). Two drain-valve fittings are also located on the front panel. The humidifier is thermally connected to the reservoir and has a thermostatically controlled heater, which is activated, when necessary, to prevent the water system from freezing. The monitor puts out two fault signals, along with concentration data: One signal indicates low water level in the humidifier and the second indicates a frozen water system.

(4) Cloud-chamber rotary valve: A rotary valve is used to control sample airflow into and out of the cloud chamber and also to control the expansion-diaphragm position. The rotor is machined to provide two two-way valves for control of sample airflow (CRV1 and CRV4, fig. 6) and two two-way valves for control of the expansion-diaphragm position. The rotor is driven at 60 rpm with a 400-hertz-hysteresis gear-head motor.

As shown in figure 6, sample air from the pressurization system enters the sensor system through a set of zero valves. For a CN measurement, the zero valves direct the flow to the humidifier. To determine the sensor output for particle-free air (first-mode control signal activated), the flow is directed first through a filter (Gillman type-A) that removes all particles and then to the humidifier. From the humidifier,

the flow passes through CRV1, through the cloud chamber, and out CRV4. Sample flow rate is controlled to 1.25 std. liters/min by the flow restrictor located downstream from CRV4. The flow-restrictor outlet and the downstream side of CRV3 are connected to a surge volume and then through a check valve to the monitor's exhaust system. The purpose of the surge-volume - check-valve combination is to reduce pressure fluctuations in the sensor system caused by variations in exhaust flow rate. The exhaust flow rate normally varies during the cyclic operation of the pressurization system.

The timing for the sequence of events in the cloud chamber is also shown in figure 6. With the cloud-chamber valve turning at 60 rpm, CRV1 and CRV4 open for 0.75 second and allow sample air to flow through the cloud chamber. Then CRV1 and CRV4 close and allow the sample to stabilize for 0.1 second in the cloud chamber. Next, CRV3 opens and applies exhaust pressure to the back of the expansion diaphragm. This increases the cloud-chamber volume and thereby reduces the cloud-chamber

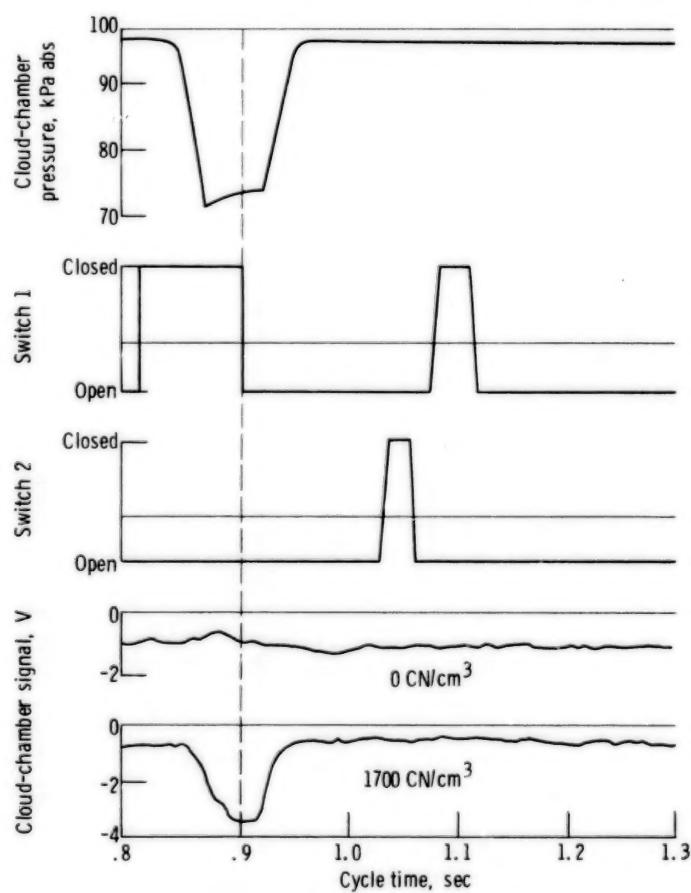


Figure 7. - Condensation-nuclei-monitor timing, expansion pressure, and cloud-chamber signals. (Cycle time is same relative time shown in valve sequence in fig. 6.)

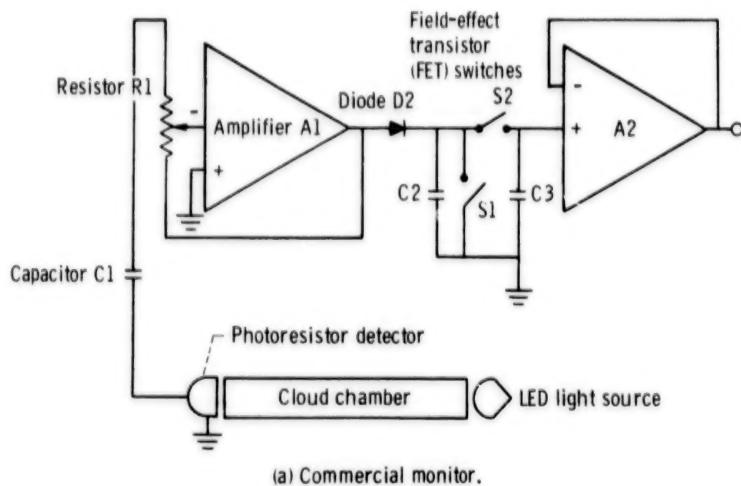
pressure. After 0.1 second, CRV3 closes and CRV2 opens and applies ambient pressure to the diaphragm. This returns the diaphragm to its normal position. The cycle repeats 0.05 second later.

Cloud-chamber pressure as a function of time was measured during the expansion process. The pressure (fig. 7) drops from 98 to 72 kilopascals absolute, for a pressure ratio of 0.73 and a calculated supersaturation of 420 percent. Because this pressure drop is a result of a volume-defined expansion, the pressure ratio is constant and independent of sample pressure. Tests indicate that the sensor will operate at pressures as low as 55 kilopascals absolute, which is well below the 72- to 82-kilopascal range of cabin pressures encountered in B-747 aircraft.

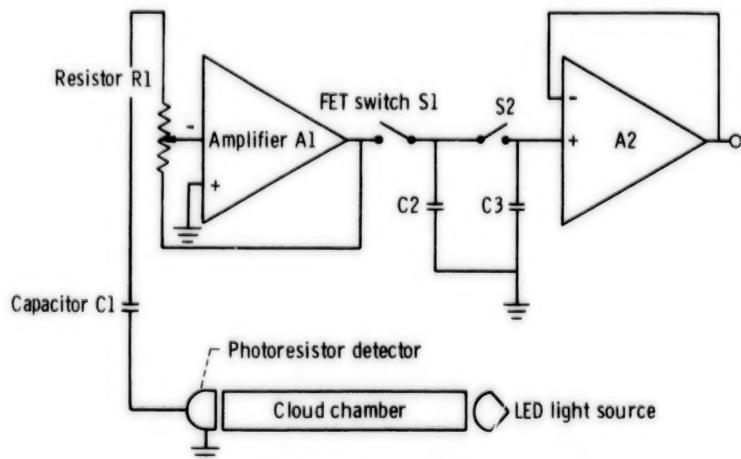
The sensor system originally contained attenuation measurement electronics identical to those furnished in Environment/One's commercial instruments. These electronics have now been modified to reduce the noise level and allow for the measurement of lower CN concentrations. In the commercial instrument, a peak read-and-hold circuit is used to measure the peak attenuation occurring during the entire expansion process. In the modified sensor, the peak read-and-hold circuit has been changed so that the attenuation is measured at a particular instant in time during the expansion.

An electrical block diagram of the attenuation measurement circuits is shown in figure 8 for both the commercial and modified monitors. In the commercial monitor (fig. 8(a)) the output voltage of amplifier A1 is rectified by diode D2 and applied to capacitor C2. Thus C2 charges to the peak voltage developed by A1, less the diode voltage drop during an expansion process. At the proper time, switch S2 closes and transfers charge between C2 and C3 until the voltages on the two capacitors become equal. Then S2 opens and the voltage on C3 is amplified and becomes the source for the instrument output voltage. Amplifier A2 is a high-input-impedance, unity-gain amplifier. Switch S1 discharges capacitor C2 between expansion cycles. The switches are operated by a shutter mounted on the cloud-chamber valve rotor, and the shutter position is optically detected by solid-state devices.

In the modified monitor (fig. 8(b)) the timing shutter is adjusted so that S1 opens at the instant that peak attenuation occurs. The actual switch-timing relative to the cloud-chamber pressure signal is shown in figure 7. This leaves capacitor C2 charged to a peak voltage indicative of the peak attenuation. A short time later, S2 closes and transfers charge between C2 and C3. The relative timing between S1 and S2 has not been changed in the modification. The second closure of S1 discharges C2 through A1's output stage. Also shown in figure 7 are typical voltage signals measured at the output of A1 for two different CN concentrations.



(a) Commercial monitor.



(b) Modified monitor.

Figure 8. - Electrical block diagram of attenuation measurement circuits.

Noise Level and Time Response

The monitor output as a function of time was recorded for a particle-free sample with the pressurization system operating (fig. 9). This recording was made over a 5-minute interval with an inlet pressure of 28 kilopascals absolute. The output generally remains within the equivalent of $\pm 10 \text{ CN/cm}^3$ over this interval. For a measurement being made at 1-second intervals, the standard deviation of this type of signal was calculated to be 5 CN/cm^3 .

The time response of the monitor is shown in figure 10. Plotted is the relative monitor output as a function of time for a step change in inlet particle concentration. The data were taken with an inlet pressure of 28 kilopascals absolute and show a time constant of approximately 6 seconds for a 63-percent change in the output signal. This time constant depends primarily on the flow system and the ratio of values of C2 to C3.

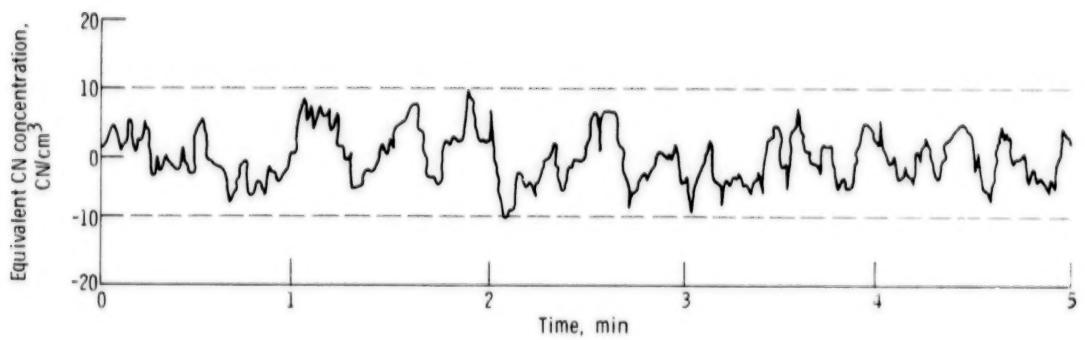


Figure 9. - Typical noise on output signal with particle-free sample air at inlet pressure of 28 kilopascals absolute.

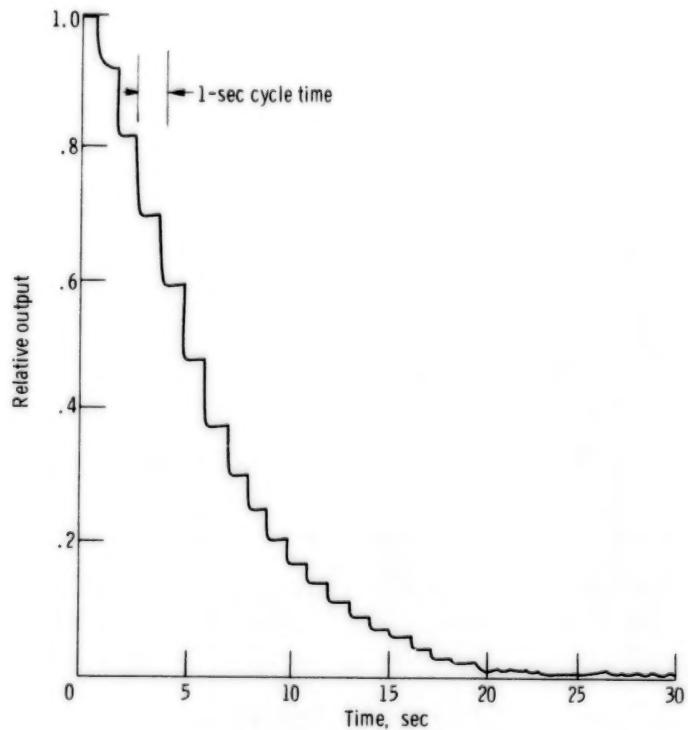


Figure 10. - Response of condensation-nuclei monitor to step change in CN concentration.

in the sensor-system electronics. The capacitors act as an electrical filter on the output signal and control the monitor noise level. Thus a trade-off must be made between monitor noise level and response time. The flow-system time constant is estimated as 1 second, and thus the capacitors are the response-limiting components in the monitor. Their values have been chosen to minimize the noise level of the output signal.

CALIBRATION

A Pollak counter, described in reference 10, is used as the standard for calibrating condensation-nuclei monitors. Although basic calibration is performed only on the sensor system, operational tests are made on the complete monitor.

A schematic diagram of the CNM calibration system is shown in figure 11. A constant-pressure air supply feeds air through a particle filter and into the particle

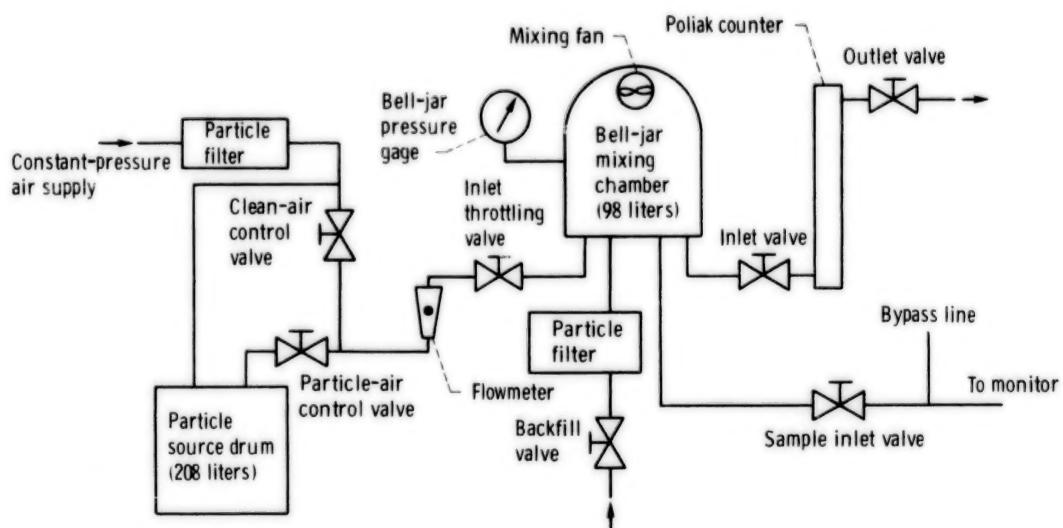


Figure 11. - Schematic diagram of condensation-nuclei-monitor calibration system.

source drum. When required, particle-laden air from the drum can be blended with clean air by using the valves labeled "clean-air control" and "particle-air control" in order to obtain a sample of a given particle concentration. The blended mixture passes through a flowmeter and an inlet throttling valve and then into the bell-jar mixing chamber. The contents of the bell jar are continuously mixed by means of a fan located in the bell jar. The flow out of the bell jar is directed to a Pollak counter and also to the CNM sensor-system inlet. For sensor-system calibration, the inlet throttling valve and the sample inlet valve are fully open. More air is supplied to the bell jar than is required by the Pollak counter and sensor system. The excess air leaves the system

through the bypass line. Sample pressure at the sensor-system inlet is thereby maintained at atmospheric pressure.

For convenience, combustion products from the burning of cotton string are used as a particle source. The cotton string is burned in the particle source drum and allowed to stand for approximately 1 hour before use. Data showing monitor output for other types of particles are given at the end of this section.

To perform a calibration test, a particular particle concentration level is established in the bell jar. After the desired concentration is obtained, particle-free air is continually added to the bell jar at a constant rate. This gives rise to exponential decay of particle concentration in the bell jar. Measuring the concentration at regular intervals with the Pollak counter yields a time history of the particle concentration in the bell jar. The concentration data are fitted to an exponential curve by the method of least squares. From this curve the concentration in the bell jar can be computed for any instant of time during the test.

The output voltage of the CNM is also recorded while the Pollak-counter measurements are being made. Periodically, the first-mode control signal is activated to obtain the monitor output voltage for a particle-free sample. After the test run, smooth curves are drawn through the recorded output voltages: one curve through the data obtained with particle-laden sample air, and the second curve through the data obtained with particle-free air. These curves average out the monitor noise level. The monitor output voltage at any time for a given particle concentration is the difference between the two curves. This voltage difference, along with the computed values of concentration in the bell jar for the same time, is used to plot the actual calibration curve for the monitor.

Bell-jar concentration is plotted as a function of time in figure 12 for a typical calibration test run. In this figure, the decay time constant is approximately 12 minutes. The flow rate through the Pollak counter was 4 std. liters/min, corresponding to a complete air change in 8 seconds. Also shown is the calculated least-squares-fit curve, which minimizes the sum of the squares of the deviation between the curve and the data points. The percent deviation of the measured data points from the least-squares-fit curve is shown in figure 13. The standard deviation of a data point from the least-squares-fit curve is 3.9 percent. Because the data points appear randomly scattered, it is concluded that both the assumption of an exponential concentration decay and the method of computing bell-jar concentration at any time are justified. It is possible that the variation in the deviation data points is a result of not having a homogeneous mixture in the bell jar even though a fan is used to induce mixing. Also, some of the variation is inherent in the Pollak-counter operation.

A typical set of calibration points is shown in figure 14 for a sensor system after its gain was adjusted, by using resistor R₁ (fig. 8), to $600 \text{ CN/cm}^3 \cdot \text{V}$. Plotted on a

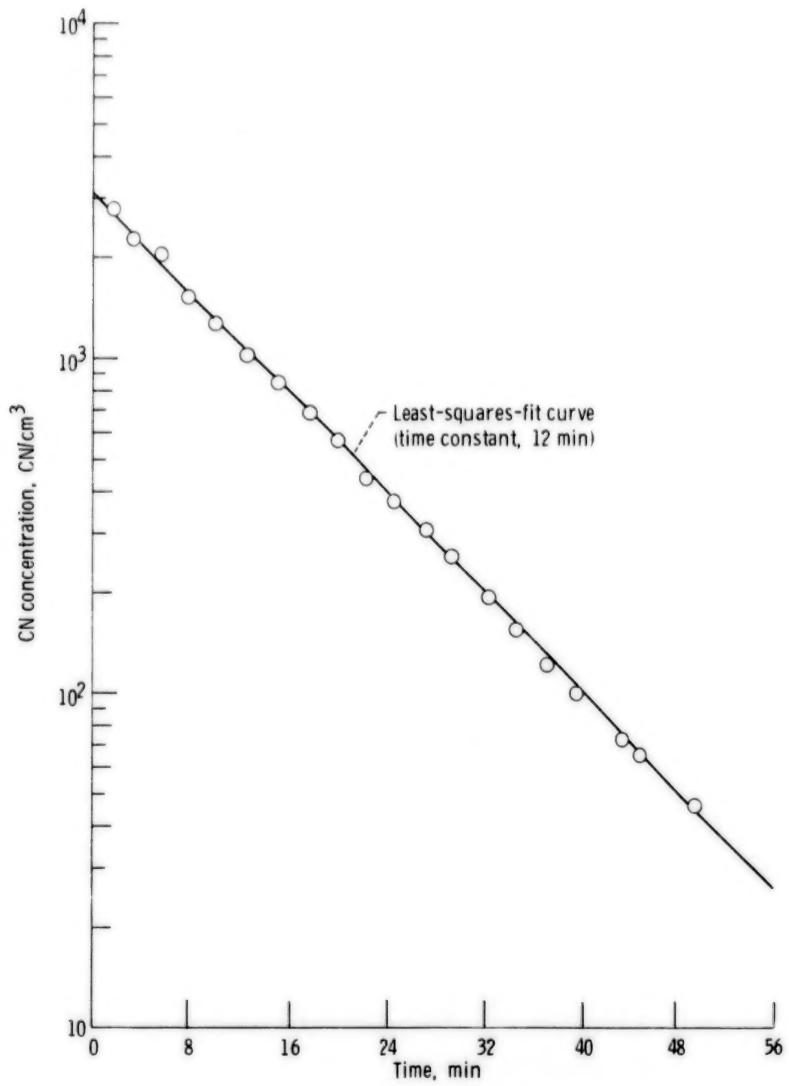


Figure 12. - Bell-jar concentration as function of time.

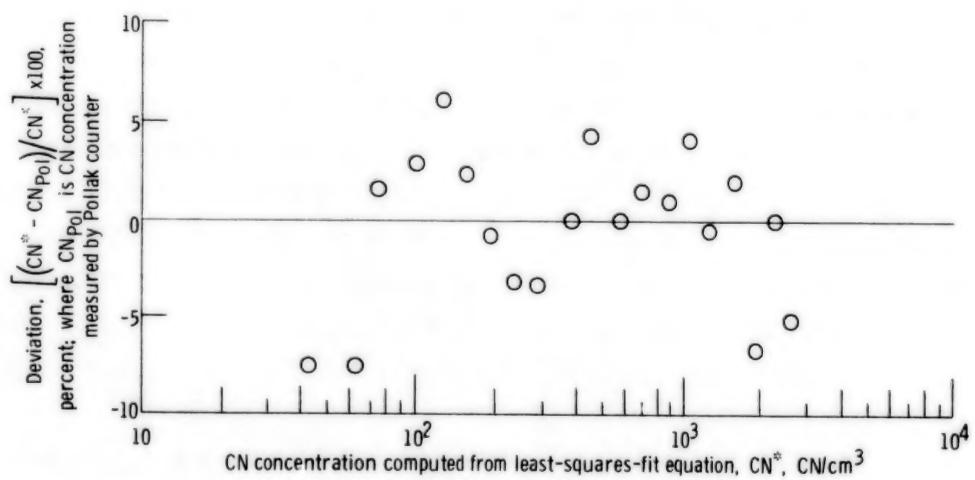


Figure 13. - Deviation of measured concentration in bell jar from exponential least-squares-data-fit curve as function of concentration.

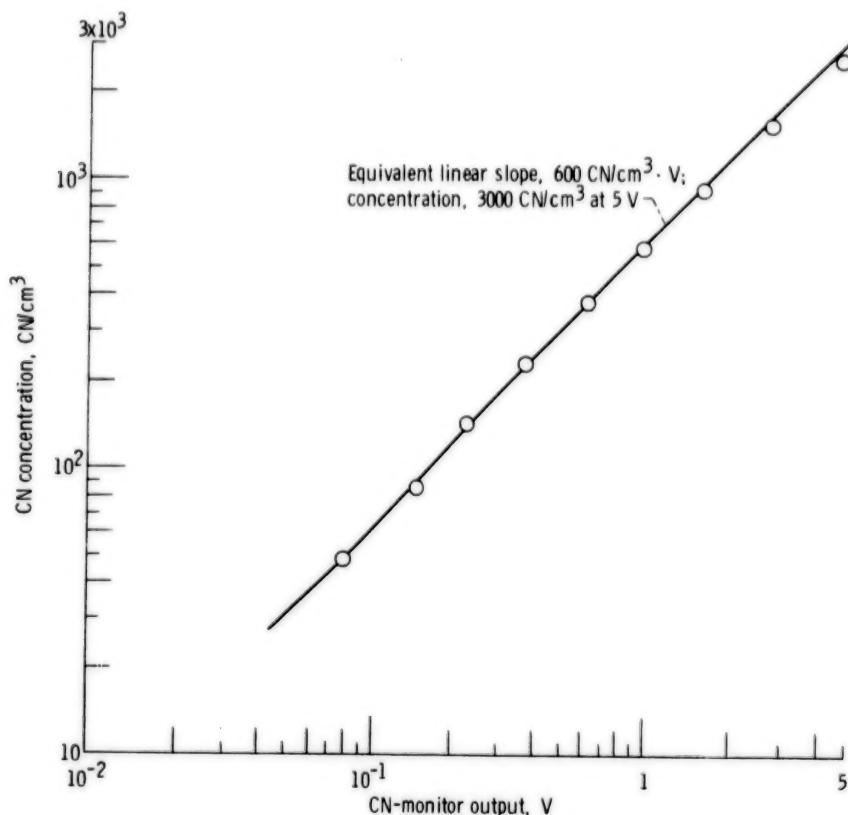


Figure 14. - Sensor-system calibration.

log-log scale is the output voltage of the monitor corrected for zero offset as a function of particle concentration. Also shown is a line that passes through the point at 5 volts and 3000 CN/cm³, with a slope of 600 CN/cm³·V. This line corresponds to the assumed linear relation between voltage and concentration used in equation (1). The percent deviation of the data points from the line is shown in figure 15. The standard deviation of these points, 4.4 percent with respect to the line, is comparable to the 3.9 percent previously mentioned for the Pollak-counter measurement of the bell-jar concentration. Thus the precision of the sensor when noise level is neglected is comparable to that of the Pollak counter, and the assumption of a linear relation between concentration and voltage is reasonable. At a concentration of 100 CN/cm³, the error in the measurement (1 standard deviation) is estimated as ± 6.6 percent of reading based on the square root of the sum of the deviations squared (where the deviations are 4.4 percent in the calibration points and 5 percent (5 CN/cm³) in the monitor noise level).

A series of calibration test runs are shown in figure 16 for four particle sources: cotton-string combustion products, heated Nichrome wire, an atomized 1-percent sodium chloride solution, and room-air particles. All the test runs were made after the

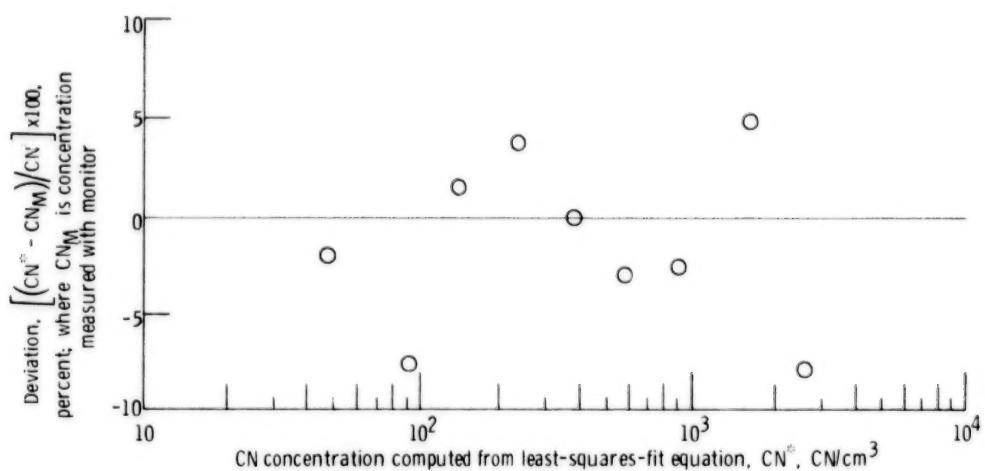


Figure 15. - Deviation of monitor calibration from linearity as function of concentration.

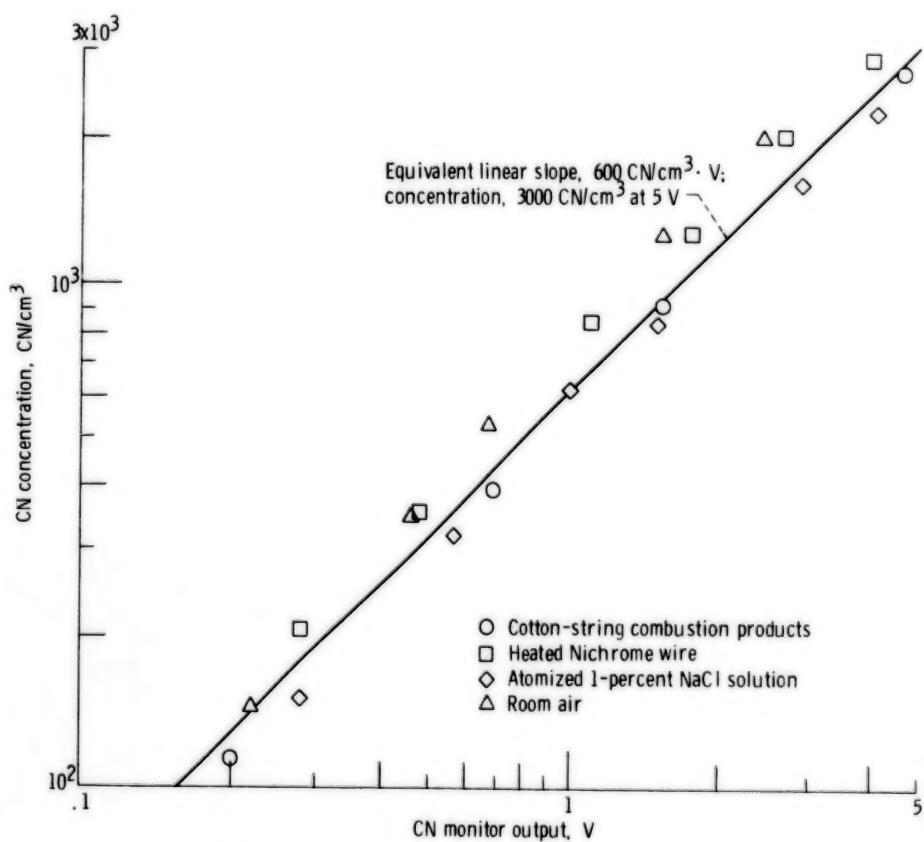


Figure 16. - Condensation-nuclei-monitor output for four particle sources.

particles had been in the bell jar for more than 1 hour. The figure indicates that the sensitivity varies by as much as ± 25 percent for the particles used in these tests. The tests were made with a Pollak counter as the measurement standard. As reference 11 indicates, the sensitivity of the Pollak counter depends somewhat on particle type. Thus, this variation in sensitivity may be associated with either the GASP monitor or the Pollak counter, or both. It is emphasized that an absolute calibration of the CNM is not being performed. However, as indicated by the previously described calibration tests, the effect on monitor output of variations in input concentration for a given type of particle is linear.

The monitors have been tested over a range of ambient operating temperatures and pressures. Calibration test runs were made at various temperatures between 5° and 50° C and at pressures between 68 and 100 kilopascals absolute. In general, most of the data points obtained at these ambient conditions were within ± 10 percent of the linear calibration curve, and no trends were found that indicated a consistent effect of temperature and pressure on sensitivity.

OPERATIONAL TESTS

Operational tests are performed on all monitors before they are put into service. The primary purpose of these tests is to check the operation of the pressurization system. For the tests, the monitor inlet is connected to the sample outlet line of the calibration system (fig. 11) and the bypass line is removed from the calibration system. With the monitor operating with a low exhaust pressure, the inlet throttling valve is adjusted until a simulated aircraft inlet pressure is achieved in the bell jar. The clean-air control valve and the particle-air control valve are adjusted to achieve a constant concentration level in the bell jar (as opposed to the time-decay method used in sensor calibration), as indicated by a constant voltage output from the monitor. After the system is in equilibrium, the inlet throttling valve and the sample inlet valve are closed. The backfill valve is then opened and the bell jar is pressurized to atmospheric pressure with particle-free air. This process maintains the same concentration in the bell jar as that which existed when the system was supplying sample air at low pressure. The Pollak counter is then used to measure the bell-jar concentration at atmospheric pressure. Equation (1) is used to convert the monitor output voltage to CN concentration. The monitor pressurization system is assumed to be operating properly if, over a series of measurements, the CN concentrations measured by the monitor are within ± 10 percent of those read by the Pollak counter.

Measurements made during an operational test are shown in figure 17. Plotted are the measured concentrations calculated by using equation (1) as a function of the Pollak-counter reading. The average difference between the CNM measurement and

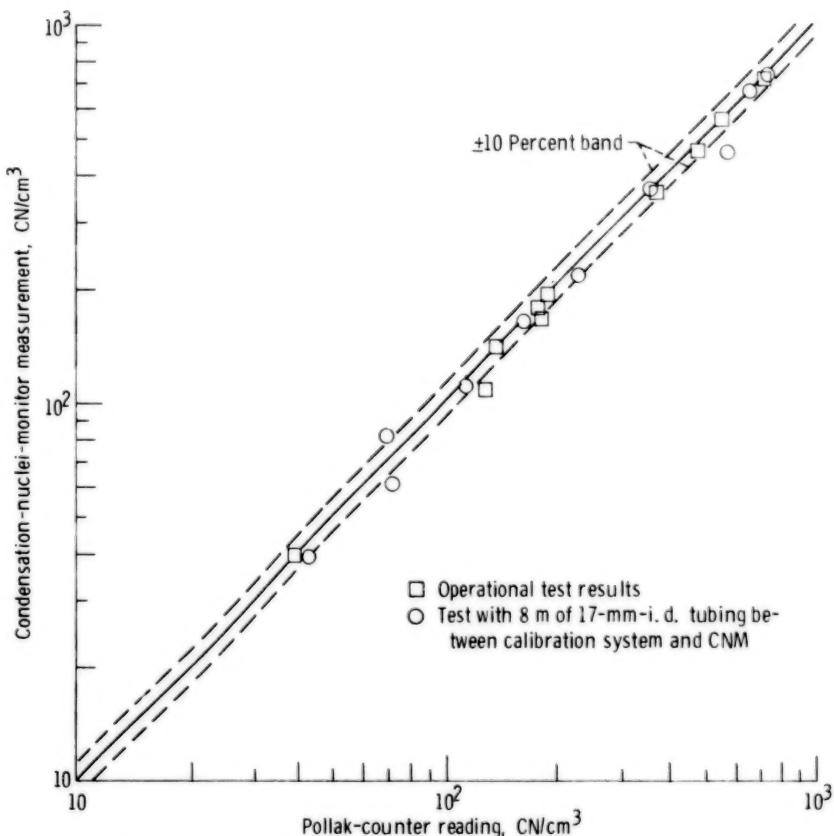


Figure 17. - Operational test results, including data for simulated inlet tube.

Pollak-counter reading is 4.2 percent, with a standard deviation of 4.3 percent. That is, approximately 4.2 percent of the particles entering the CNM are lost in the pressurization system. Also plotted in figure 17 is a set of data taken when an 8-meter length of 17-millimeter-inside-diameter tubing was installed between the calibration system and the CNM. These data were taken to obtain an indication of the particle loss that may be expected in the aircraft-installation flow system. The average difference between the CNM measurements and Pollak-counter readings was 4.5 percent, with a standard deviation of 7 percent. Since the average difference is about the same with and without the inlet tubing, apparently no real particle loss occurred when the inlet tubing was used. Based on the diffusion loss calculations discussed previously, this indicates that the particles used in the calibration and in the operational test are probably larger than 0.01 micrometer in diameter.

TYPICAL MEASUREMENTS

Condensation-nuclei monitors have been flying as part of the GASP system since October 1977. A typical set of measurements made with a monitor is shown in fig-

ure 18. These data were recorded on a special meridian flight around the world by a B-747 SP aircraft operated by Pan American World Airways. The flight began on October 28, 1977, from San Francisco and went over the North Pole to London and then to Capetown, South Africa. From Capetown, the flight went over the South Pole to Auckland, New Zealand, and from there directly back to San Francisco. The flight lasted 54 hours with 2-hour refueling stops in London, Capetown, and Auckland.

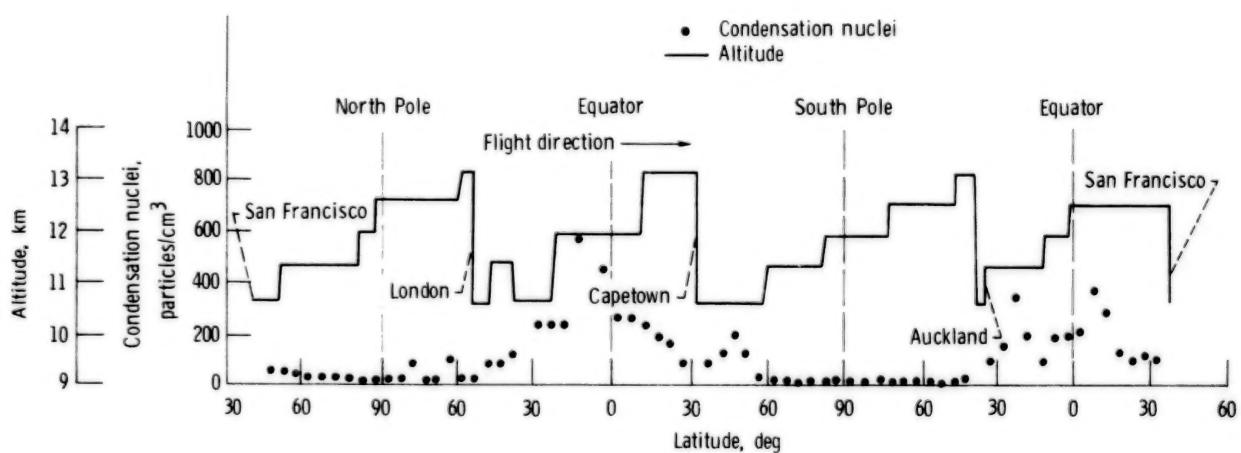


Figure 18. - Condensation-nuclei measurements from meridian flight around world.

Plotted in figure 18 are the average CN concentrations measured over 5-degree latitude bands. Also plotted is the aircraft flight altitude. The measured concentration reached $600 \text{ CN}/\text{cm}^3$ near the equator over South Africa. Near the North and South Poles and over ocean portions of the flight route, measured concentrations were generally below $25 \text{ CN}/\text{cm}^3$.

SUMMARY OF RESULTS

The concentrations of condensation-nuclei particles are being measured as part of the NASA Global Atmospheric Sampling Program. The CN monitor used for these measurements is a modified version of a commercial instrument made by Environment One Corp. of Schenectady, N.Y. NASA has replaced the pressurization systems purchased with the monitor by an "air piston" system and has changed the electronics and timing so that concentrations of less than $10 \text{ CN}/\text{cm}^3$ can be measured. The full-scale monitor output at flight conditions is approximately $1000 \text{ CN}/\text{cm}^3$. The output of the monitor sensor is linear with concentration. The sensor is capable of making measurements with an error (1 standard deviation) of ± 6.6 percent of reading at concentrations above $100 \text{ CN}/\text{cm}^3$ when calibrated against a Pollak counter with a given type

of particle. The sensitivity of the monitor sensor system varies by as much as ±25 percent relative to that of the Pollak counter for four types of particles. This change in sensitivity is typical of what would be expected for this type of monitor and calibration system. The particle loss in the pressurization system is estimated to be 4 to 5 percent.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, November 30, 1978,
198-10.

APPENDIX - CERTIFICATION AND RELIABILITY-AND-
QUALITY-ASSURANCE TEST PROGRAMS

A test program was developed to certify the condensation-nuclei monitor for operation on a B-747 aircraft flying in commercial service. This test program was based on the philosophy that the monitor should not interfere with, or create a hazardous condition during, the operation of the aircraft. Primary emphasis was placed on testing for electromagnetic interference compatibility and on determining if any problems resulted when the monitor was operated on an aircraft power system. Also included in the program were shock and vibration tests.

Electromagnetic interference testing was based on the procedures given in Boeing Co. standards for aircraft systems. Tests were made for both interference generation and susceptibility effect. Power-line filters were the only components added to the monitor in order to be within the measurement limits specified in Boeing Co. standards. Similarly, tests were made to determine if any problems resulted from operating with various steady-state ac voltage and frequency combinations that might be encountered on B-747 aircraft. Operational tests were performed under both normal and abnormal transient power conditions. The test procedures were based on Boeing Co. standards.

Shock and vibration tests were performed according to procedures described in reference 12 (paragraphs 6 and 7). Some additional vibration tests were performed by NASA to ensure that components were securely fastened and to determine that no chafing problems existed in the internal wiring. Experience has shown that shocks encountered in normal handling and shipping are much more severe than those specified in the test procedure even though the monitors are shipped in padded containers.

A reliability-and-quality-assurance test program was also developed for the monitor. This program involved a burn-in test, requiring 168 hours of operation, and thermal cycling tests. The thermal cycling tests consisted of cycling the monitor between 60° and -40° C twenty times. Some motor bearing problems showed up in these tests, but no electrical failure occurred. As a result of the calibration, operational, certification, and reliability-and-quality-assurance test programs, more than 400 hours of operating time accumulate before a CNM is placed in service.

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1. Report No. NASA TP-1415	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle CONDENSATION-NUCLEI (AITKEN PARTICLE) MEASUREMENT SYSTEM USED IN THE NASA GLOBAL ATMOSPHERIC SAMPLING PROGRAM		5. Report Date February 1979	
7. Author(s) Ted W. Nyland		6. Performing Organization Code	
9. Performing Organization Name and Address National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135		8. Performing Organization Report No. E-9816	
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		10. Work Unit No. 198-10	
15. Supplementary Notes		11. Contract or Grant No.	
		13. Type of Report and Period Covered Technical Paper	
		14. Sponsoring Agency Code	
16. Abstract The condensation-nuclei (Aitken particle) measuring system used in the NASA Global Atmospheric Sampling Program is described. Included in the paper is a description of the condensation-nuclei monitor sensor, the pressurization system, and the Poilak-counter calibration system used to support the CN measurement. The monitor has a measurement range to 1000 CN/cm ³ and a noise level equivalent to 5 CN/cm ³ at flight altitudes between 6 and 13 km.			
17. Key Words (Suggested by Author(s)) Pollution monitoring; Condensation nuclei; Calibration technique; Instrumentation; Aircraft; Aitken particle		18. Distribution Statement Unclassified - unlimited STAR Category 45	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 27	22. Price* A03

* For sale by the National Technical Information Service, Springfield, Virginia 22161

NASA-Langley, 1979

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Sept. 14, 1979